Carderock Division
Naval Surface Warfare Center
Bethesda, Md. 20084–5000

CARDIVNSWC–TR–61—94/14 March 1995
Survivability, Structures, and Materials Directorate
Technical Report

Comparison of Cathodic Protection Currents on 70/30 Copper-Nickel and Alloy 625 Piping Systems

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ABSTRACT

The objective of this study was to determine whether the demand on a cathodic protection system changes when the protected pipe material is changed from copper-nickel to alloy 625. Two piping mockups were designed to simulate a probable geometry for a cathodically protected piping system. Each mockup consisted of a 20-ft (610-cm) length of nominal 2-in.- (5-cm-) diameter piping with a zinc anode for cathodic protection inserted in the discharge end of each. One mockup was made with 70/30 copper-nickel pipe and the other with alloy 625 pipe. Protection currents and potential profiles inside the pipes were measured over a 6-month exposure period in natural seawater flowing at 7 ft/s (210 cm/s). The total protection current and sacrificial anode consumption for alloy 625 pipe were half that for copper-nickel pipe. Thus, replacing copper-nickel pipe with alloy 625 pipe in areas close to cathodically protected heat exchangers or hulls will result in less demand on the cathodic protection system, as opposed to the original copper-nickel piping.

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ADMINISTRATIVE INFORMATION

This project was sponsored by the Naval Sea Systems Command, Code PMS 350T14 (M. Peterson). Work was conducted under work unit 1–2813–801 in the Marine

Corrosion Branch, Code 613, under the direction of Mr. Robert Ferrara. Outfitting and testing of the piping mockups were conducted by Mr. David Greenlaw of the Carderock Division, Naval Surface Warfare Center (CARDEROCKDIV, NSWC) and by the staff of the LaQue Center for Corrosion Technology, under the direction of Mr. Robert Kain and Mr. Dennis Melton.

ABBREVIATIONS

C	Coulomb
CARDEROCKDIV, NSWC	Carderock Division, Naval Surface Warfare Center
id	Inside diameter
ksi	Kips (1,000 lb) per square inch
od	Outside diameter
ppm	Parts per million
PVC	Polyvinyl chloride
ZRA	Zero-resistance ammeter

INTRODUCTION

With the increasing use of advanced materials for piping systems, problems of compatibility with existing materials and systems sometimes arise. One such situation arises if a cathodically protected structure such as a heat exchanger, which has performed well in a seawater-filled piping system constructed of 70/30 copper-nickel, is placed in an identical piping system constructed of alloy 625. A similar situation arises if 70/30 copper-nickel piping exiting to the outside of a cathodically protected structure is replaced with alloy 625.

In both cases, the question to be answered is whether the demand on the cathodic protection system will change when the protected pipe material is changed from copper-nickel to alloy 625? On the one hand, the polarization resistance of alloy 625 is greater than that of 70/30 copper-nickel because of its lower corrosion rate,[1] meaning that less current is required per unit area to provide a given level of cathodic protection to alloy 625 than to the copper-nickel. At first glance, it would, therefore, seem that the alloy 625 pipe will require less cathodic protection current. Countering this is the change in Wagner number for a material with a larger polarization resistance. The Wagner number[2] is the ratio of the polarization resistance to the electrolyte resistance. This ratio is proportional to a characteristic distance through which current will flow. A higher Wagner number means that current will travel farther along the inside of an alloy 625 pipe than it will along a copper-nickel pipe.[3] This results in more effective surface area of alloy 625 absorbing the cathodic protection current as opposed to a copper-nickel pipe, increasing the total protection current required. The objective of this research was to determine which of these effects, i.e., differences in current density or differences in effective area, would dominate, or will piping made of alloy 625 require a greater or lesser amount of cathodic protection current than 70/30 copper-nickel?

APPROACH

Two piping mockups were designed to simulate a probable geometry for a cathodically protected piping system. Each mockup consisted of a 20-ft (610-cm) length of nominal 2-in. (5-cm) diameter piping with a zinc anode for cathodic protection inserted in the discharge end of each, as indicated in Figure 1. One mockup was made with 70/30 copper-nickel pipe, the other with alloy 625 pipe. These mockups were constructed and operated at the LaQue Center for Corrosion Technology, Wrightsville Beach, N.C.

MATERIALS AND CONSTRUCTION

One 20-ft section of nominal 2-in. (5-cm) pipe was procured of each material. Alloy 625 (UNS N06625) welded tubing was procured to ASTM B 705,[a] class 2, of April 1982. 70/30 copper-nickel (UNS C71500) type 1 seamless tubing was procured to MIL–T–16420K(SH)[b] of April 14, 1978, grade 1, except that the wall thickness and inside diameter were required to be that of the nominal 2-in.- (5-cm-) diameter pipe. All pipe was schedule 40, 2.375 in. (6.03 cm) od by 2.067 in. (5.25 cm) id by 0.154 in. (0.39 cm) wall thickness. Mechanical properties and chemical compositions of the piping alloys are shown in Table 1.

[a] "Specification for Nickel-Alloy (UNS N06625 and N08825) Welded Pipe."

[b] "Tube, Copper-Nickel, Seamless and Welded (Copper Alloy Numbers 715 and 706)."

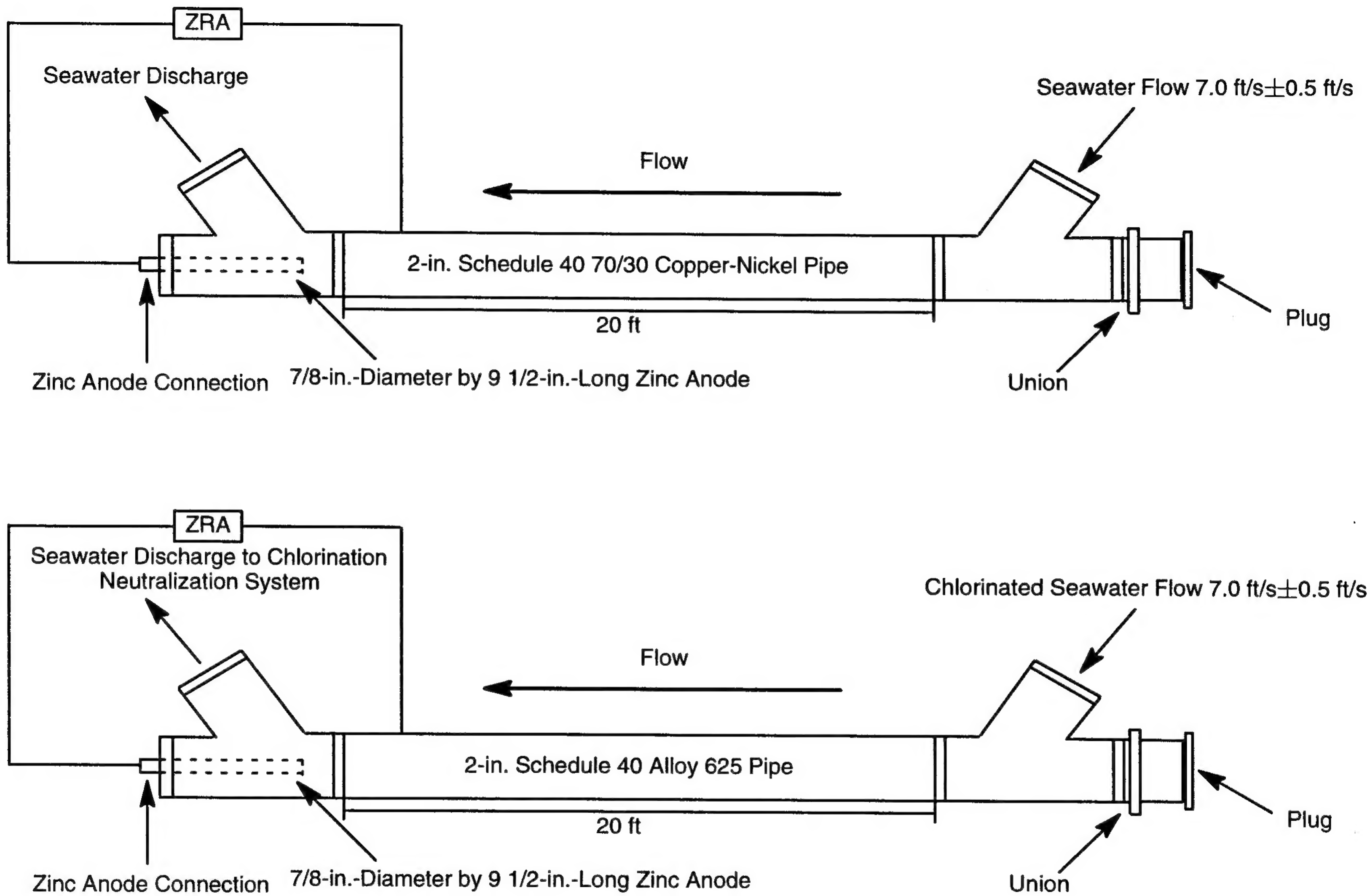


Figure 1. Schematic of piping mockups.

Table 1. Compositions and mechanical properties of materials tested.

Alloy:	Copper-Nickel	Alloy 625
Supplier:	Tioga Pipe Supply Co., Inc.	Haynes International, Inc.
Heat or Lot:	Order A36442	Heat 2650–0–6782
Form:	2-in. (5-cm) pipe	2-in. (5-cm) pipe
Composition	Weight %	Weight %
Cu	67.86	–
Ni	30.34	60.00
Fe	0.93	4.30
Mn	0.74	0.24
Zn	0.46	–
C	0.030	0.02
S	0.016	<0.002
P	0.006	<0.005
Pb	0.002	–
Ti	–	0.31
Si	–	0.22
Nb+Ta	–	3.42
Mo	–	8.87
Cr	–	21.62
Co	–	0.13
Al	–	0.18
Mechanical Properties		
Ultimate Tensile Stress, ksi (MPa):	60.4 (416)	139.9 (965)
Yield Stress, ksi (MPa):	22.5 (155)	68.2 (470)
Elongate in 2-in., %:	45.5	45.5

Polyvinyl chloride (PVC) compression sealing fittings were used to connect sections of pipe to the manifolds, the rotameter, and other system components. Figure 2 shows several of these fittings. The main seawater supply line to the mockup assembly was a nominal 6-in. (15-cm) PVC pipe. Service to individual mockups was achieved by tapping this 6-in. (15-cm) manifold with nominal 4-in. (10-cm) tee connectors. Nominal 2-in. (5-cm) PVC globe valves were used, along with nominal 4-in. (10-cm) by 2-in.

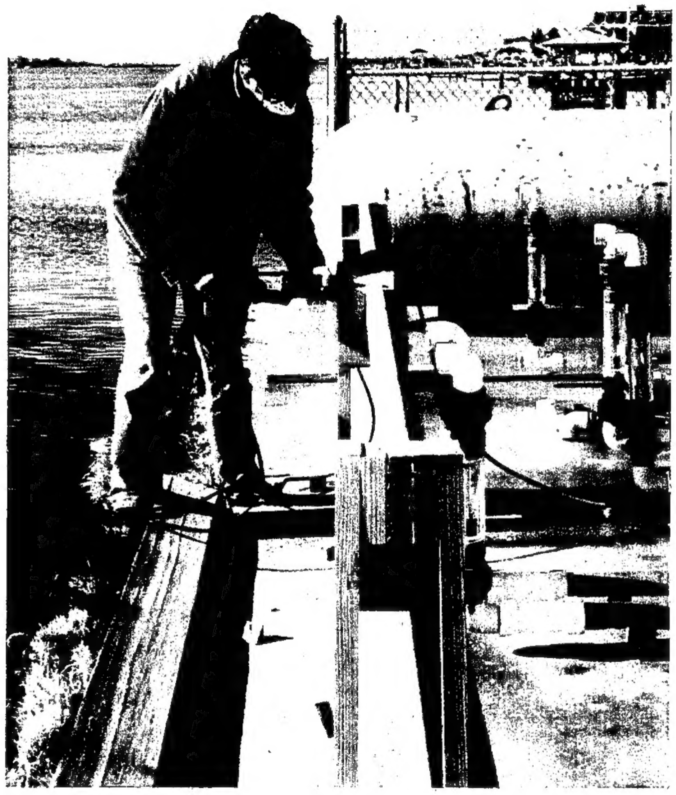


Figure 2. PVC fittings on ends of the mockups.

(5-cm) reducers, to regulate the flow of seawater to each mockup. A rotameter was inserted in the discharge end of each mockup (see Figure 3).

A cathodically protected structure was simulated by the use of a nonmetallic housing with a sacrificial zinc rod, as shown in Figure 4. Zinc anode material designated ZRN in military specification MIL–A–18001H[c] was procured in the form of a 6-ft- (180-cm-) long by 7/8-in.- (2.2-cm-) diameter bar. Anodes for each mockup were cut off of the bar stock in lengths of 9 1/2 in. (24.1 cm). These nominal dimensions gave an anode-to-cathode area ratio of approximately 1 to 60. The anodes were drilled, tapped, and mounted in PVC plugs. A 10-gauge alloy 625 wire was attached to the surface of each test pipe with two hose clamps. Prior to this, the pipe and wire were sanded down to base metal in order to remove any type of scale, film, or deposit. Electrical contact grease was then applied to the sanded area of the pipe before the alloy 625 wire was clamped into place. The lead wire from each zinc anode was connected to the alloy 625 lead wire on the pipe with a wire nut. Before assembly, the anodes were degreased with acetone and weighed to the nearest 0.1 g. To avoid interference with the flow of seawater, the anodes were placed on the discharge ends of the pipes instead of the inlet ends.

EXPERIMENTAL PROCEDURE

70/30 copper-nickel has inherent antifouling characteristics.[4] Alloy 625 does not possess similar behavior and can suffer from a heavy accumulation of these growths, which may cause blockage of piping. By chlorinating the seawater, fouling can be averted. To establish a better simulation for the comparison of the cathodic protection requirements of alloy 625 and 70/30 copper-nickel, the alloy 625 mockup was, therefore, electrolytically chlorinated at a continuous low level of 1.0 ppm plus or minus 0.2 ppm. The mockups were operated for 6 months. The flow maintained in each mockup was 7 ft/s (210 cm/s).

CURRENT MEASUREMENTS

Current measurements were made between the sacrificial zinc rod and the pipe sections using a zero-resistance ammeter (ZRA). Current measurements were performed daily for the first week of the exposure and then weekly for the remainder of the exposure. The ZRA was connected only when the readings were actually being taken. At other times the zinc and pipe sections were maintained in electrical contact by external wiring. To avoid interruption of current flow while connecting the ZRA, it was first hooked up parallel to the regular system wiring. Then, the normal wiring was disconnected while the current flow was measured with the ZRA. The regular wiring was reconnected before the ZRA wiring was disconnected at the conclusion of the measurement.

POTENTIAL MEASUREMENTS

Protection potential measurements were made in 1-ft (30-cm) increments from the seawater inlet side to the discharge end of the pipes several times during the exposure. An Ag-AgCl reference electrode was mounted in a very long probe (shown schematically in Figure 5). In the design of the probe, the following major objectives were desired:

[c]"Anodes, Sacrificial Zinc Alloy."

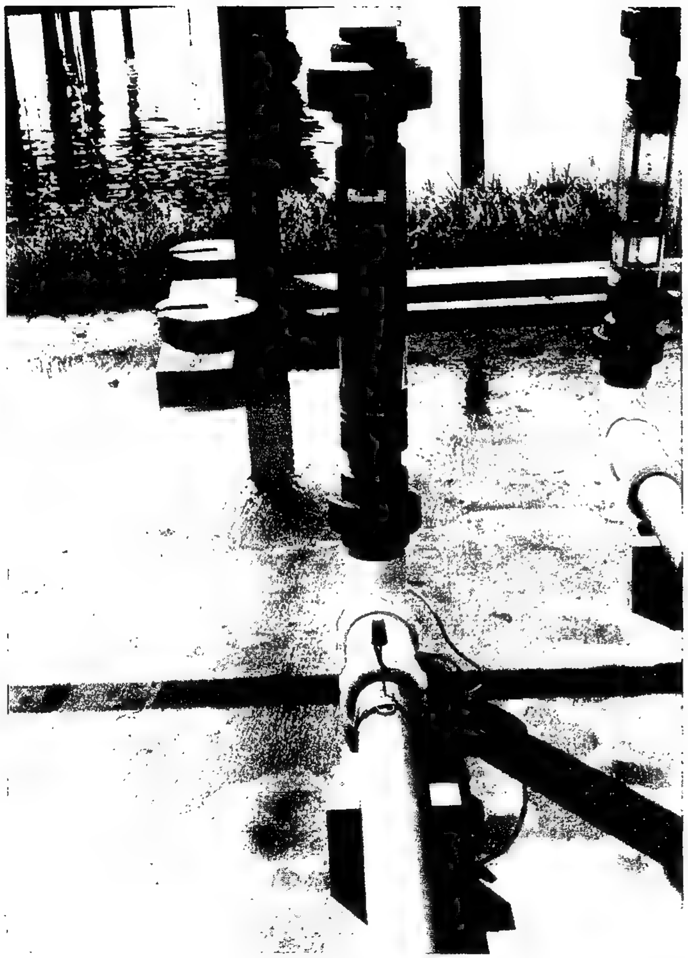


Figure 3a. Alloy 625 chlorinated mockup.

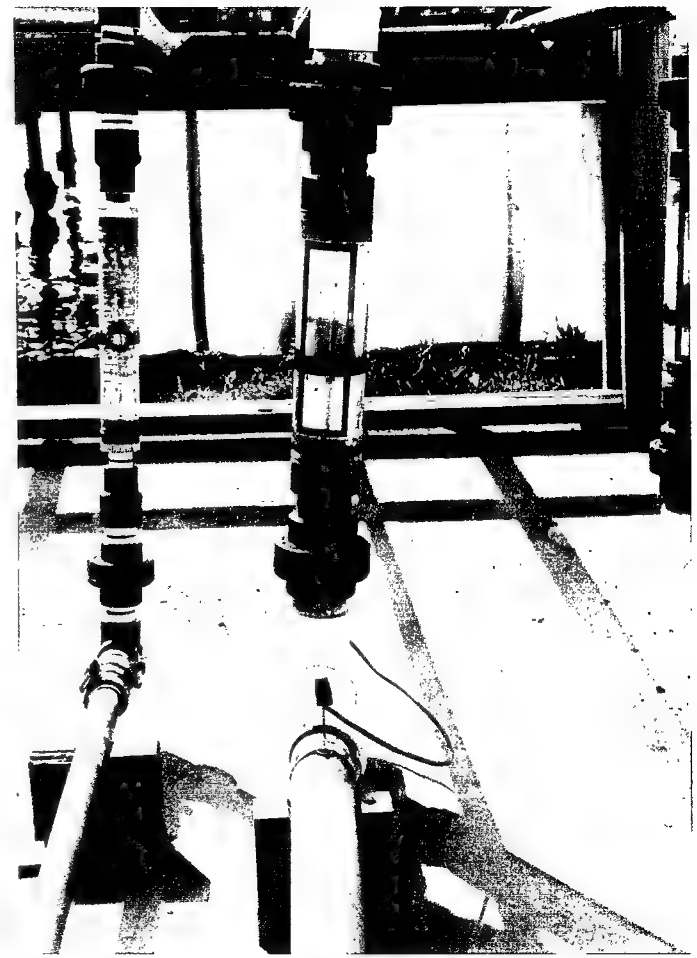


Figure 3b. Copper-nickel mockup.

Figure 3. Rotameters in discharge ends of mockups.

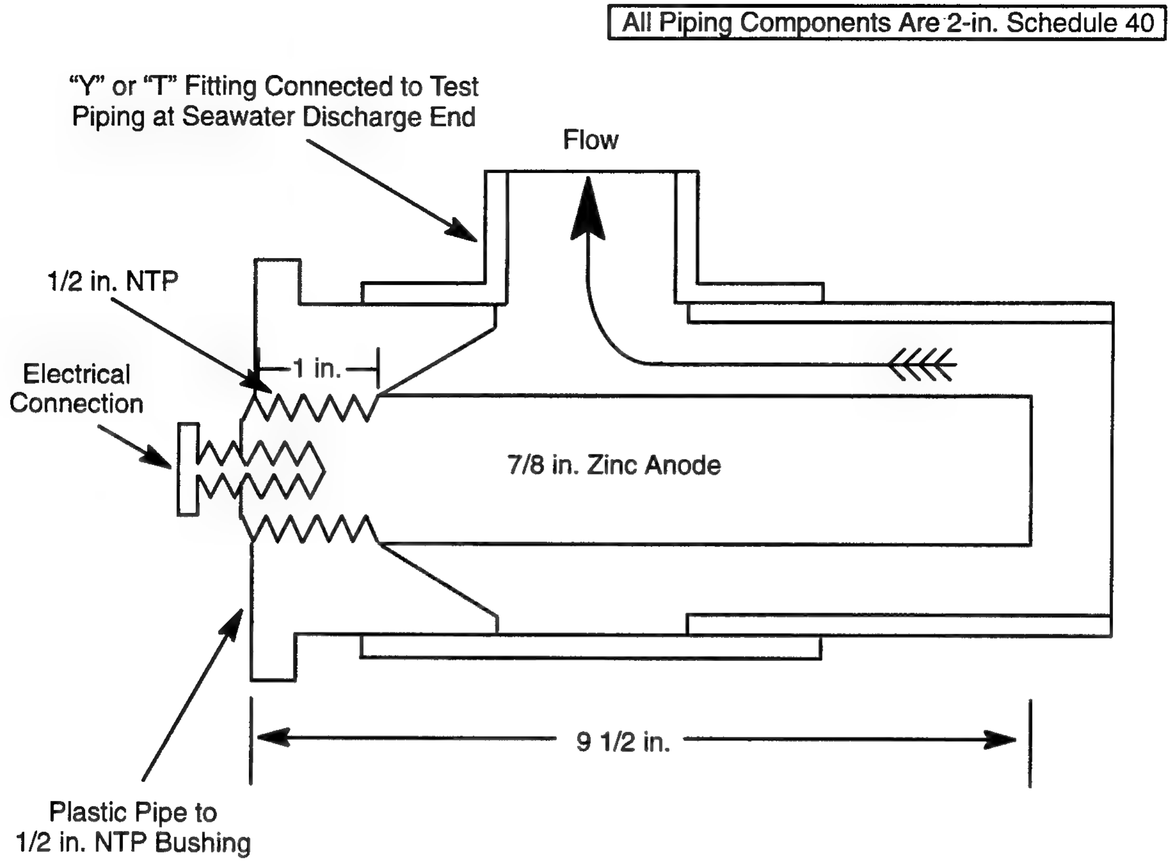


Figure 4. Anode holder.

1. To allow potential measurements to be made in each mockup while seawater was flowing under normal test conditions;
2. To have no interruptions in the other mockup while measurements were being made;
3. To maintain the reference electrode in the center of each pipe during the course of the measurement;
4. To seal the electrical lead wire against contact with the seawater.

The scraping force of the probe against the pipe walls was also designed to be at a minimum. These goals were achieved through the use of PVC in the construction of the probe and the pipelines.

The "upstream" end of each tee connection on the seawater inlet end of each mockup had a screw-on plug that was used during normal operations of the system. When potentials were taken, the incoming water was shut off with the PVC globe valve and the plug was unscrewed and replaced with the reference electrode probe. Then the seawater flow was restarted and adjusted. After the system stabilized, the potentials were measured. Initially, one set of readings was taken traversing down the length of the pipe from the seawater inlet end (inserting the probe). Later, a set of readings was also taken while

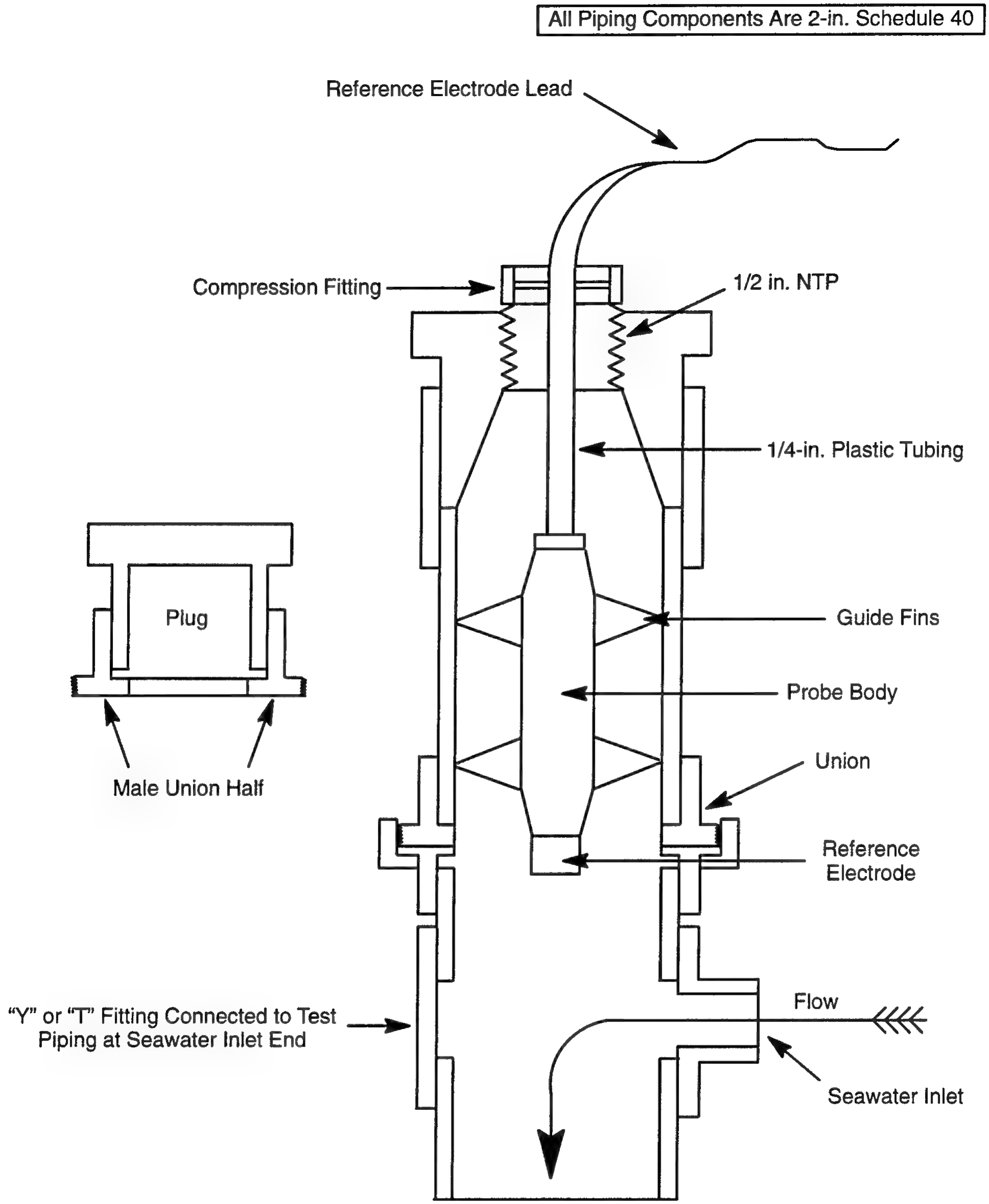


Figure 5. Potential measuring probe.

withdrawing the probe from the pipe. The second set was taken because of the possibility that the probe guide fins might damage the corrosion products on the inner walls of the pipe. Significant differences between the "in" and "out" potentials would have indicated this occurrence. The flexible plastic tubing, which covered the reference cell lead wire and acted as a push rod for the reference cell assembly, was later changed to rigid plastic tubing after it was discovered that the flexible tubing was kinking and not stretching out to its full extent inside of the test pipes. Thus, the potential readings taken just before this probe reconstruction had inaccuracies in longitudinal positioning.

PHYSICAL MEASUREMENTS

At the conclusion of the exposure, the pipes were lightly cleaned with a stiff brush to remove large fouling organisms, rinsed, and returned to CARDEROCKDIV, NSWC for evaluation. Corrosion of the interior surfaces was not observed, and so no measurements were taken. The pipes were split in half lengthwise to observe calcareous deposit formation.

RESULTS AND DISCUSSION

GALVANIC CURRENTS

Table 2 lists the currents measured between the zinc anodes and the copper-nickel and alloy 625 pipe sections as a function of exposure time. This information is plotted in Figure 6. Currents started small, then increased to a steady-state value after 20 to 30 days. Steady-state currents to the alloy 625 pipe were roughly half those of the copper-nickel pipe. The total charge passed over the test period was obtained by integrating the current/time data to get values of 6.28×10^5 C for the copper-nickel and 2.64×10^5 C for the alloy 625. Assuming a two-electron charge transfer, this comes out to a theoretical weight loss for the zinc anodes of 212.1 g and 89.1 g for the anodes connected to the copper-nickel and alloy 625 pipes, respectively. Actual weight loss for these anodes was 215.1 and 107.1 g, respectively, giving an anode efficiency of 97.6 percent for the anode connected to the copper-nickel and 89.1 for the anode connected to the alloy 625. The reason for the large difference in efficiency is unknown, but the chlorination may provide additional anodic reactions in the alloy 625 mockup.

The anode connected to the copper-nickel was consumed at twice the rate of that connected to the alloy 625. This can be seen in Figure 7, where the anode connected to the copper-nickel is significantly shorter. Anode wastage was conical at the anode tip. This is reasonable because the tip was closest to the pipe being protected and the tip was also within the flow stream, while the body of the anode was located in a dead-end leg of the mockup.

POTENTIALS

Table 3 lists the potential data for both mockups as a function of distance as the reference probe was inserted, and then withdrawn. These same data are plotted in Figure 8. Potentials matched well between the insertion and withdrawal. The copper-nickel potential leveled off 5 to 6 feet from the anode end of the pipe, whereas the alloy 625 potential did not level off until about 13 to 15 feet from the anode end of the pipe. This indicated that protection current travels farther down the alloy 625 pipe than down the copper-nick-

el pipe. This is consistent with Wagner number analysis, as stated previously. The reason that the potentials turn slightly more negative at the pipe end farthest from the anode is unknown.

Table 2. Measured protection currents (mA) between anodes and pipes.

Date	Days	Copper-Nickel	Alloy 625
3/11/91	4	0.19	0.20
3/12/91	5	0.18	0.18
3/13/91	6	2.38	1.39
3/14/91	7	2.53	1.18
3/20/91	13	22.1	14.2
3/28/91	21	51.2	19.2
4/5/91	29	58.2	23.3
4/11/91	35	59.7	23.3
4/18/91	42	53.0	24.0
4/25/91	49	54.0	26.0
5/2/91	56	58.0	27.0
5/10/91	64	61.0	27.0
5/16/91	70	68.0	28.0
5/24/91	78	64.0	28.0
5/30/91	84	66.0	28.0
6/6/91	91	62.0	24.0
6/13/91	98	60.0	20.0
6/27/91	112	59.0	21.0
7/18/91	113	42.0	21.0
8/6/91	152	Removed	Removed

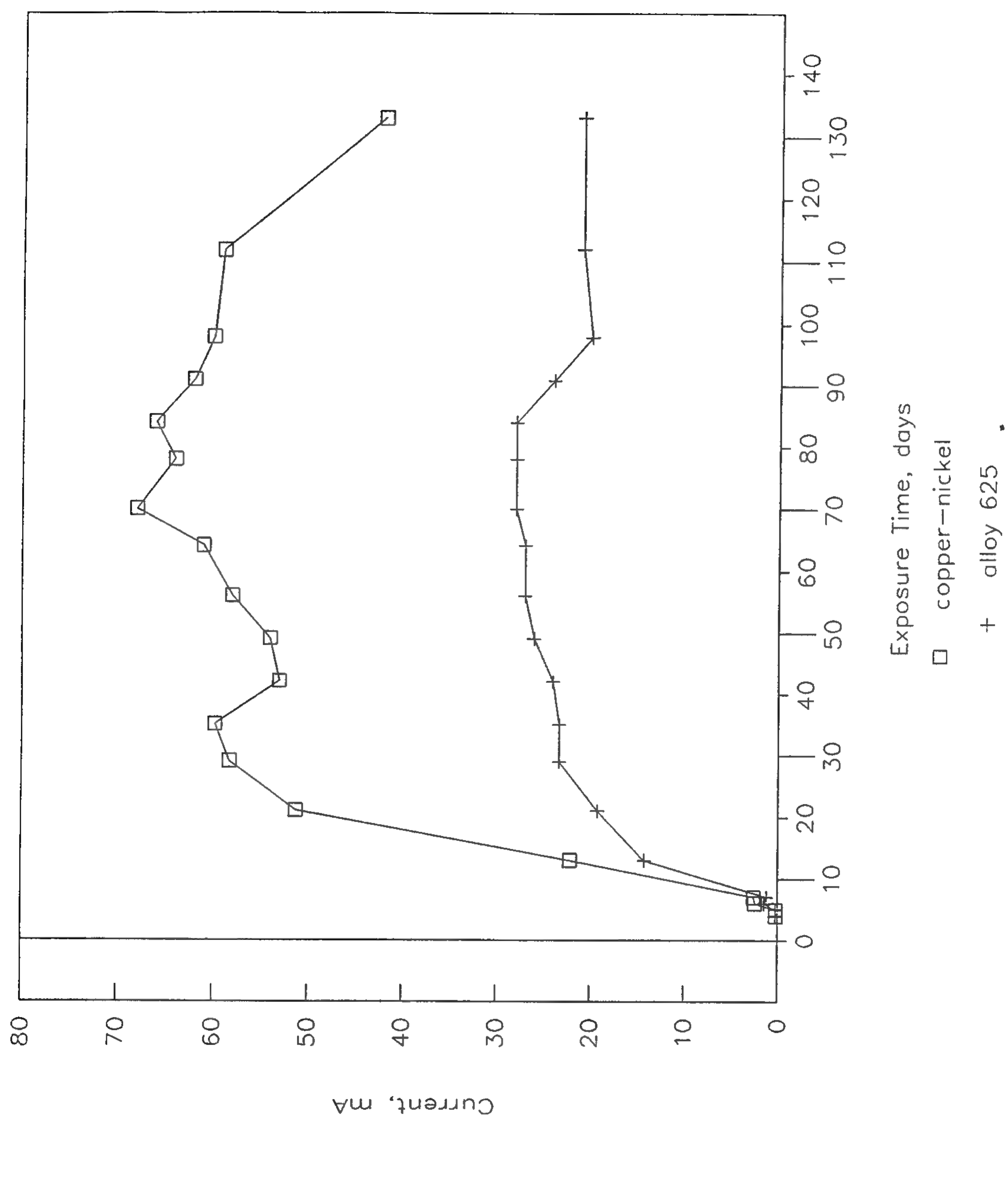
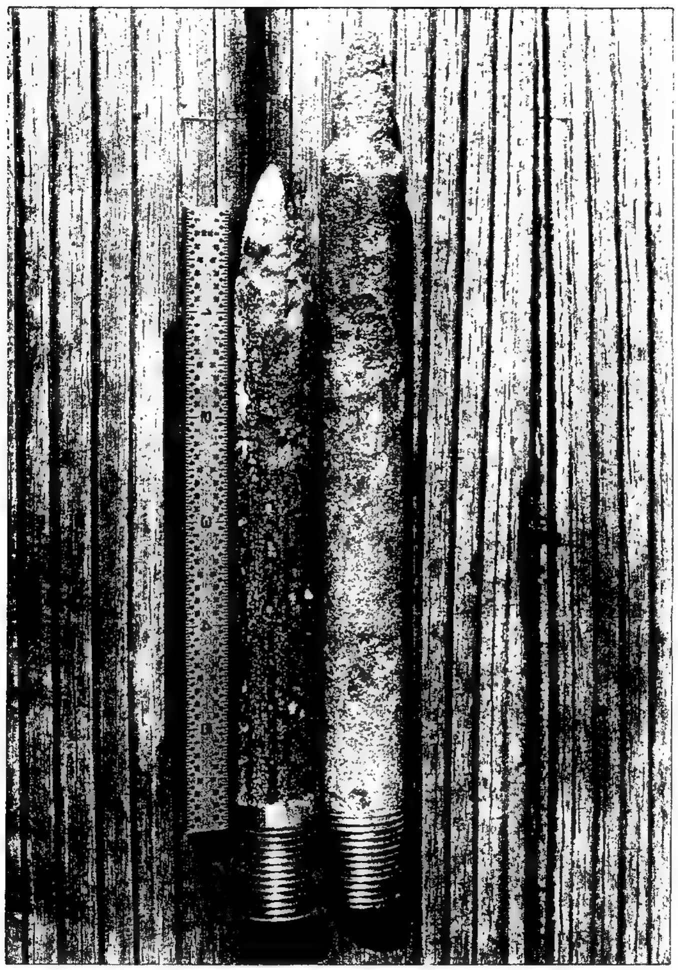


Figure 6. Measured currents between anodes and pipes.



Copper-Nickel Mockup (on left) Alloy 625 Mockup (on right)

Figure 7. Zinc anodes after test.

Table 3. Potentials (mV) on the inside of the pipes (July 8, 1991).

	Copper-Nickel		Alloy 625	
Feet	In	Out	In	Out
22	–296	–295	–180	–164
21	–279	–285	–170	–157
20	–263	–270	–140	–145
19	–249	–261	–115	–123
18	–240	–250	–93	–108
17	–231	–242	–81	Bad Data
16	–225	–232	–73	–84
15	–221	–228	–69	–65
14	–217	–221	–70	–67
13	–214	–219	–76	–70
12	–212	–219	–89	–84
11	–213	–219	–109	–96
10	–216	–221	–131	–120
9	–220	–225	–160	–149
8	–227	–229	–195	–180
7	–240	–238	–234	Bad Data
6	–263	–259	–278	–269
5	–307	–301	–331	–325
4	–370	–362	–393	–400
3	–464	–460	–480	–486
2	–648	–615	–610	–600
1	–930	–932	–776	–782
0	–	–	–1,019	–1,001

VISUAL OBSERVATIONS AND PHYSICAL MEASUREMENTS

The alloy 625 mockup was found to be covered with a brown deposit after the conclusion of the exposure. Similar deposits have been found in exposures of other materials whenever chlorination is used.[5] The deposit is most easily visualized by reference to the photographs of the two rotameters in Figure 3. The darker rotameter was from the chlorinated alloy 625 mockup.

Little fouling was noted in either pipe material. Light calcareous deposits were observed on both pipe mockups. They were extremely tenacious and were most prominent on the pipes closest to the anodes. It was not possible to visually compare the calcareous deposits on the two pipes due to the interference from the brown deposit from the chlorination.

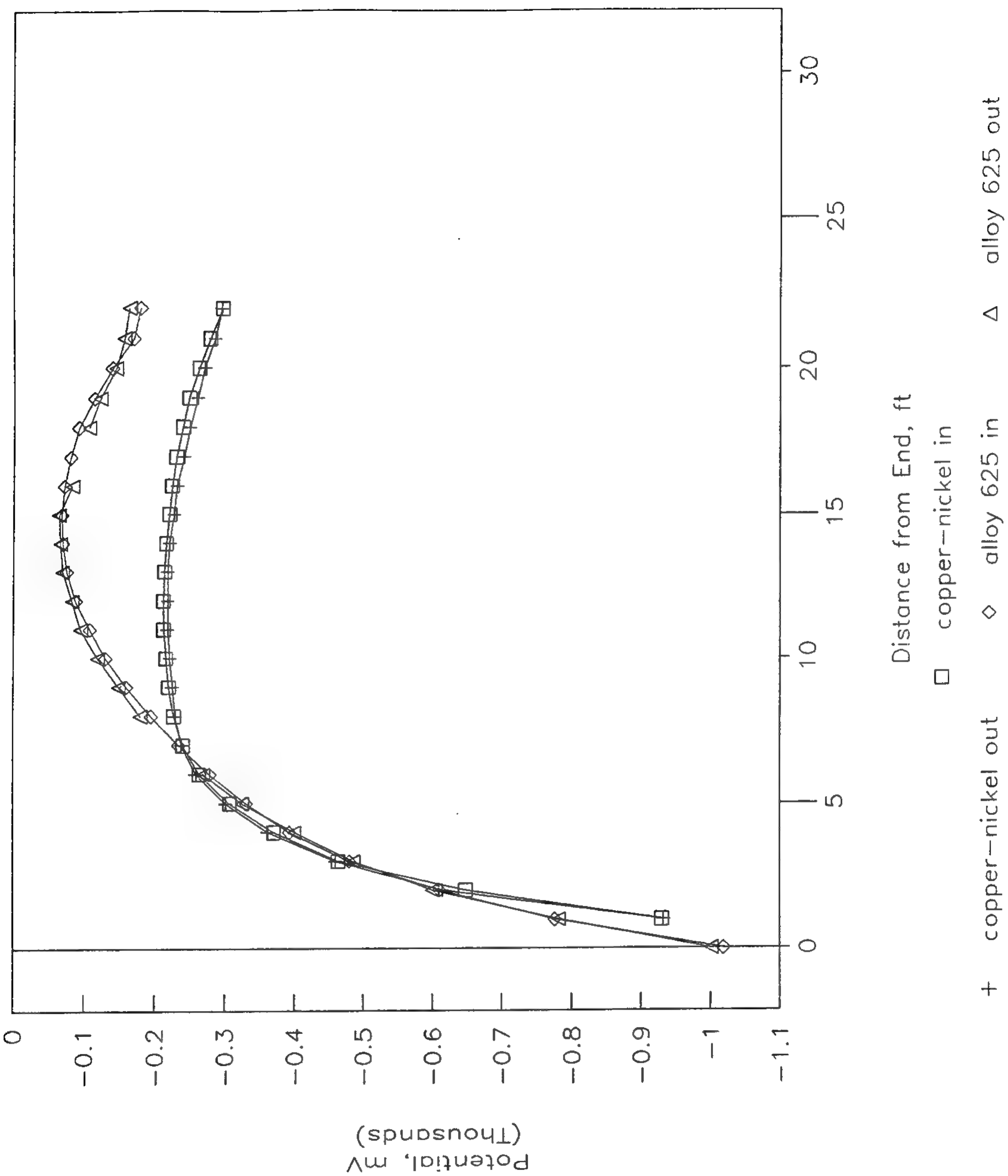


Figure 8. Potentials on the inside of the pipes.

CONCLUSIONS

Protection current extended much farther down the inside of the alloy 625 pipe than down the copper-nickel pipe, as predicted by Wagner number analysis. The total protection current and sacrificial anode consumption for alloy 625 pipe was, however, half that for the copper-nickel pipe. Thus, replacing copper-nickel pipe with alloy 625 pipe in areas close to cathodically protected heat exchangers or hulls will result in a design for the cathodic protection system where the anodes will last longer, as opposed to the original copper-nickel piping.

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